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RELATION OF SURFACE WINDS TO PRESSURE GRADIENTS

BY C. S. DURST, B.A.

During the war it was desired to know what was the most probable surface wind for a given geostrophic wind. A certain amount of information on this subject is given by Shaw* but there does not seem to be available in meteorological literature a comparison of the frequencies of different wind speeds with the associated pressure gradients. To remedy this lack, certain months and hours were examined by using the winds recorded at Gorleston and comparing these with the simultaneous pressure gradients measured off the working charts. The measurements of geostrophic winds were made by Mr. C. F. J. Jestico and much of the calculation and tabulation was done by him.

The data were arranged according as the pressure gradients were on shore (between NE. and SE.) or off shore (between SW. and NW.). The months used were May, June, July and August 1936–40 representing summer, using the two hours 0100 and 1300 G.M.T. For winter the months January and December 1936–40 were used and the four hours 0100, 0700, 1300 and 1800 were included.

In addition the Beaufort letters of past weather at Mildenhall during the 6 hours before each synoptic hour were tabulated as giving a general indication of the state of the sky over the land since it was felt that this would show the relation of the development of land and sea breeze to convection.

The data were discussed by making out the frequencies of the ratio of surface wind to geostrophic wind. These ratios were plotted and are shown in Figs. 1 and 2. The modes of the curves in these diagrams were then assembled in Tables I and II.

Table I indicates the diurnal variation and Table II the relation of the ratio to the steepness of gradient.

The broad conclusions are:—

(1) On-shore winds are approximately four fifths the geostrophic wind in winter and two thirds in summer.

*SHAW, SIR NAPIER; Manual of Meteorology. Vol. IV. Meteorological calculus: Pressure and wind. Cambridge, revised edition, 1931.

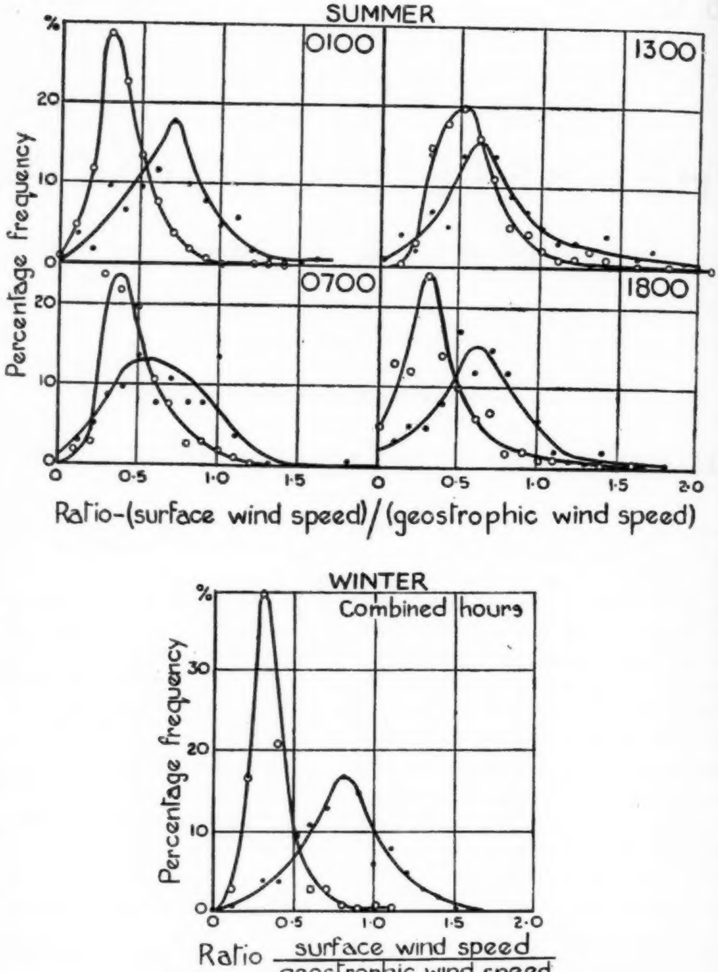


FIG. 1—SEASONAL AND DIURNAL VARIATION OF RATIO OF SURFACE TO GEOSTROPHIC WIND

(2) There is practically no diurnal variation in the ratio in winter.

(3) Off-shore winds are approximately one third of the geostrophic wind in winter and just over two fifths in summer.

(4) In summer there is a marked diurnal variation. The off-shore winds are relatively weak at night and relatively strong in the day-time.

(5) With a geostrophic speed of less than 20 m.p.h., the on-shore wind has a wide range of speed and may even exceed the geostrophic; the off-shore wind is less scattered at night but has about the same scatter in the day-time.

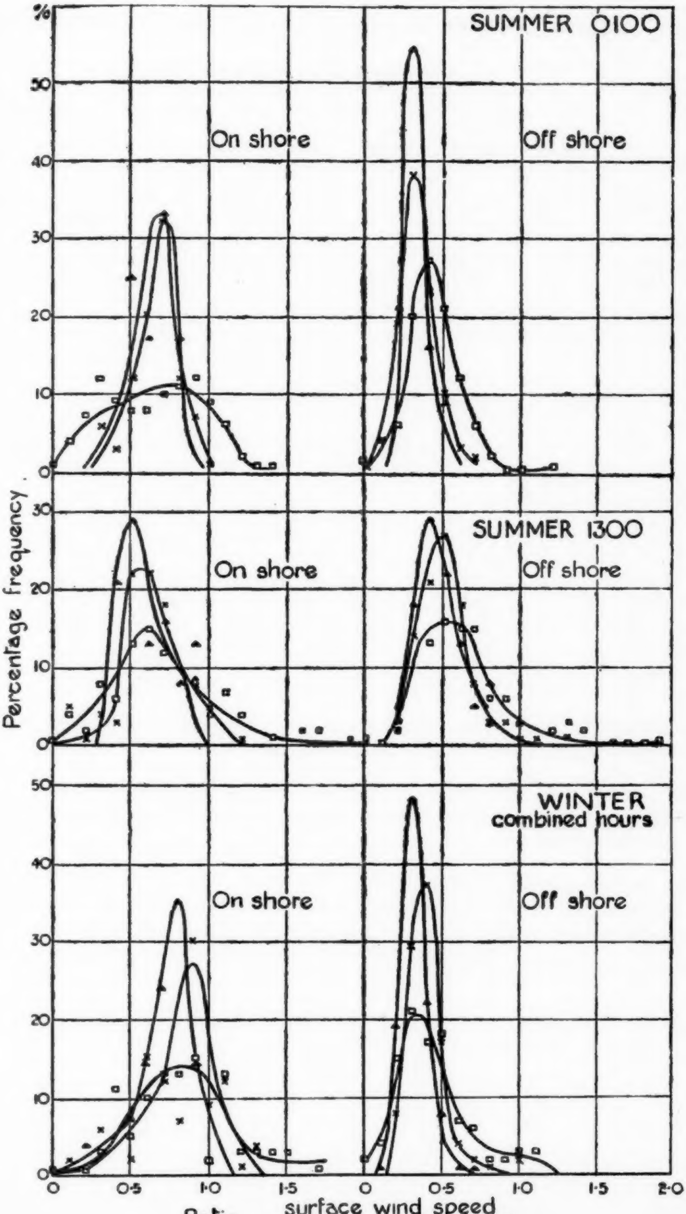


FIG. 2—VARIATION OF RATIO OF SURFACE TO GEOSTROPHIC WIND WITH WIND SPEED

TABLE I—DIURNAL VARIATION OF RATIO: (SURFACE WIND)/(GEOSTROPHIC WIND)

	Time of observation (G.M.T.)							
	0100		0700		1300		1800	
	on shore	off shore	on shore	off shore	on shore	off shore	on shore	off shore
Winter Dec., Jan.	0·75	0·32	0·82	0·32	0·75	0·35	0·83	0·30
Summer May, June,	0·65	0·39	0·62	0·52	0·63	0·58	0·64	0·46
July, Aug.	0·70	0·35	0·75	0·41	0·92	0·49	0·63	0·30
All summer months	0·67	0·36	0·65	0·45	0·65	0·52	0·63	0·38

TABLE II—VARIATION OF THE RATIO WITH WIND SPEED

	Time	9–17 kt. (10–19 m.p.h.)		18–26 kt. (20–29 m.p.h.)		27–35 kt. (30–39 m.p.h.)	
		on shore	off shore	on shore	off shore	on shore	off shore
	G.M.T.						
Winter Dec., Jan.	0100	0·87	0·40	0·88	0·44	0·77	0·26
	1300	0·75	0·37	0·82	0·36	0·77	0·33
Summer May–Aug.	0100	0·65	0·42	0·68	0·32	(0·73)	0·32
	1300	0·66	0·59	0·60	0·49	0·55	0·45

In Table III the modes are given of the ratios when the skies over the land were mainly clear, broken, and overcast.

The state of the sky inland is no great help in deducing the surface wind from the geostrophic wind in winter, but in summer the more cloudy the mid-day sky the more nearly will the on-shore wind approach the geostrophic.

The data so arranged gave no information on the direction of surface wind in relation to the pressure gradient. Table IV sets out the mean values of the geostrophic wind together with its standard scalar deviation and the vector mean values of the surface wind together with its standard vector deviation.

TABLE III—VARIATION OF MOST PROBABLE VALUE OF THE RATIO WITH THE VARIOUS STATES OF THE SKY OVER THE LAND

	Time	Mainly clear sky		Broken skies		Overcast	
		on shore	off shore	on shore	off shore	on shore	off shore
	G.M.T.						
Winter Dec., Jan.	All hours	0·72	0·32	0·82	0·34	0·80	0·32
Summer May–Aug.	0100	0·65	0·39	0·58	0·34	0·75	0·36
	1300	0·54	0·43	0·63	0·55	0·75	0·49

TABLE IV—MEAN VALUES OF SURFACE AND GEOSTROPHIC WINDS

	Time	No. of obs.	Geostrophic wind	Standard deviation	Surface wind*		Standard vector deviation
	G.M.T.		kt.	kt.	°	kt.	kt.
Winter							
Off shore	0100	76	27	12	33	8	8
	0700	67	28	17	33	8	5
	1300	83	29	14	30	10	7
	1800	68	31	10	36	9	8
	All hours	294	28	14	32	9	7
On shore	0100	53	20	10	24	14	10
	0700	51	20	10	24	14	10
	1300	48	20	8	25	15	8
	1800	53	20	10	24	16	9
	All hours	205	20	10	24	14	10
Summer							
Off shore	0100	204	17	8	37	6	4
	1300	187	18	9	39	7	8
On shore	0100	81	15	7	39	9	6
	1300	100	15	7	45	8	7

*Angle given is that between gradient and surface wind directions.

Thus it is seen the surface wind on the average lies at an angle of 30–40° to the isobars with off-shore winds, but in winter with on-shore winds it is only 24° to the isobars. The correlation coefficient of the surface wind with the geostrophic wind is comparatively small, being no more than about 0·4 or 0·5 with both on-shore and off-shore winds.

DEW-POINT TABLES—A NEW PROCEDURE

By E. G. BILHAM, B.Sc., D.I.C.

Meteorological Office practice for the computation of vapour pressure and thence of dew point and relative humidity from the dry-bulb and wet-bulb temperature, is based on the Regnault formula

$$x = f - Ap(t - t')$$

where x = vapour pressure at the time of observation

f = the saturation vapour pressure at the temperature t' of the wet bulb

p = the pressure of the air

t = the temperature of the dry bulb

t' = the temperature of the wet bulb

A = a constant depending on the speed of the air past the wet bulb and on the scale of temperature used.

For observations in Fahrenheit degrees made with an aspirated psychrometer or with an aircraft psychrometer flying near the surface, the value adopted for Ap is 0·37 when the wet-bulb temperature is above 32°F. and 0·33 when the wet-bulb temperature is 32°F. or below. Under the latter conditions the wet bulb is assumed to be covered with ice.

Confining attention for the moment to the case of wet-bulb readings above freezing point, the multiplier of $(t - t')$ may be written in the form $0{\cdot}37\,p/1000$,

p being the pressure at the place of observation in millibars. If f is also expressed in millibars, the formula gives the vapour pressure x in millibars. From this, the dew point is at once obtained by ascertaining, from a table of saturation vapour pressures, the temperature t_d for which x is the saturation pressure over water.

When readings are taken near sea-level it is usual to disregard the day-to-day variations of p, the barometric pressure, and to base the computation on the assumption that p is constant and equal to 1000 mb. It is clearly necessary, however, to take the variations of p into account when readings are made from an aircraft flying at a substantial height. At the pressure of 500 mb., which is normally reached in ascents during meteorological reconnaissance flights, the value of the multiplier $Ap/1000$ is only half its value at ground level, and a table computed on the assumption $p = 1000$ mb. is therefore inapplicable. The main object of this note is to describe a new procedure for taking account of the variation of pressure.

Hitherto it has been the practice to use separate relative humidity tables for levels 1000 mb., 900 mb., 800 mb., . . . 400 mb. The dew point, if required, was then derived from a table with the dry bulb and the relative humidity as arguments. The aircraft humidity tables in use prior to January 1949* were based on the definition:—

$$\text{Relative humidity} = \frac{\text{actual vapour pressure}}{\text{saturation vapour pressure at dry-bulb temperature}} \times 100,$$

the saturation vapour pressure referring to ice at temperatures below freezing point. By a resolution at Washington, 1947, supercooled water is substituted for ice as the basis of computation with effect from January 1, 1949. For this reason, and also because the Conference of Directors had recommended the adoption of the new Goff-Gratch tables of saturation vapour pressures as the basis of hygrometric tables, it became necessary *inter alia* to recompute the tables for use with aircraft observations.

When the matter was examined it was realised that there were substantial advantages in using the wet bulb rather than the dry bulb as the primary argument in the construction of humidity tables. One very obvious advantage —though perhaps a minor one—is that the range of temperature to be covered would be much reduced because even in the tropics wet-bulb readings exceeding 85°F. are rare. A much more important advantage becomes evident when we consider the correction for pressure. Suppose we have constructed a " basic " vapour-pressure or dew-point table corresponding to $p = 1000$ mb. with wet bulb and depression of wet bulb as arguments. We see at once from Regnault's formula that we can use this same table for a pressure of 500 mb. by merely halving the observed depression of wet bulb before entering the table. Similarly for any pressure level, p, the basic table is valid if we replace the actual depression of wet bulb by the " adjusted " depression $(t - t')p/1000$.

Instead, therefore, of a whole series of tables computed for different values of p, we need only one table (corresponding to $p = 1000$) plus a subsidiary table for obtaining the " adjusted " depression from the observed values of actual depression and pressure.

*London, Meteorological Office. Tables for obtaining values of relative humidity of the air from readings of an aircraft aneroid barometer and aircraft psychrometer in degrees Fahrenheit. London, 2nd edn., 1945.

This procedure can be used for the construction of tables for deriving either the vapour pressure or the dew point from aircraft observations of wet bulb and depression of wet bulb. The basic table can also obviously be used, without any adjustment of the depression of wet bulb, for surface observations with an aspirated or whirling psychrometer. The "adjusted" depression procedure cannot, however, be applied to a table for obtaining the relative humidity from aircraft observations. When this is required it is necessary to determine the dew point first and then refer to a second table in which the relative humidity is tabulated for known values of dry bulb and dew point.

For purposes of upper air analysis it is important that aircraft observations should be readily comparable with observations from radio-sondes. Also, it is important that the data provided by aircraft on the low-level legs of meteorological reconnaissance flights should be readily comparable with surface observations from ships and shore stations. In the new Washington codes, humidity is reported in the form of dew point in all these cases. It has therefore been decided that the revised edition of aircraft humidity tables should be in the form of a dew-point table, with wet bulb and depression of wet bulb as arguments, with a subsidiary table for obtaining the "adjusted" depression for any value of pressure down to 400 mb. These tables are printed on the obverse side of a card (Form 2628, revised 1949). On the reverse side of the card is a table reproduced from Part III of the "Handbook of weather messages, codes and specifications" from which dew point is obtained from readings of dry bulb and relative humidity. This table is primarily intended for use at radio-sonde stations, but it can equally well be used, in combination with the table on the obverse, for calculating the relative humidity from aircraft observations.

The substitution of wet bulb for dry bulb as the primary argument in setting out a hygrometric table may be somewhat repugnant to computers used to the older form of table. The widespread use of the humidity slide-rule has, however, I venture to think, prepared the minds of many meteorologists to accept the thesis that the new procedure is really the more natural and logical, having regard to the shape of Regnault's formula.

THE HOLLERITH CARD SYSTEM APPLIED TO UPPER AIR DATA

By D. DEWAR, B.Sc.

The Hollerith card system was adopted for upper air work by the British Meteorological Office in January 1948 to deal with the large and increasing amount of data being obtained from upper air observing stations. Observations are punched on the cards at the stations and sent to a central office at the end of each month where only a small staff is required for the administrative side of the system. When sufficient data have been collected this staff will be able, using machine sorting and tabulating methods, to produce all the statistical information available about upper air conditions over the British Isles and along many of the Empire air routes.

Cards for a few remote stations such as the Falkland Islands and the ocean weather ships are puched at the London Headquarters from the data sent in by the stations. Altogether, just over 130,000 cards a year are being collected so an efficient filing and indexing system is essential.

A Hollerith card is a thin piece of cardboard, $7\frac{1}{2}$ in. × $3\frac{1}{4}$ in. with 80 columns of numerals running from 0 to 9 in each column. Headings for the columns are printed to meet the requirements of the user of the card. Upper air cards have headings for date, time, place, units, etc., at the beginning of each card, followed by headings giving for different pressure levels the observations for those levels: wind direction and speed on wind cards; temperature, humidity, height of the pressure level and supplementary information on temperature cards. There are two cards for upper winds and three for upper air temperature and humidity. Figs. 1 and 2 show the cards on a reduced scale.

Observations are recorded on the cards by punching small rectangular holes at the appropriate place on the card using a Hollerith punching machine. This has a set of keys numbered 0 to 9 and two " overpunch " keys, marked " X " and " Y " respectively; the base plate of the machine has a scale numbered 0 to 80 along which moves a pointer attached to a sliding card carriage, indicating the column in which the hole will be punched. Suppose a temperature of -15°F. at the 500-mb. level (about 20,000 ft.) is to be recorded. To overcome the difficulty of minus temperatures 200 is added to all temperatures so this 500-mb. temperature would be punched as 185. The carriage is set so that the pointer is against the appropriate column number and the 1, 8, 5 keys depressed in turn. The carriage holding the card moves automatically to bring the next column into position after a key has been depressed. The overpunch keys are used to save a column being provided for a figure which would only be required occasionally. They punch holes one or two lines, respectively, above the row of numerals in a column. Relative humidity, for example, is usually less than 100 per cent.; when a reading of 100 per cent. occurs 00 is punched and also an overpunch above the first 0 to show that a 1 precedes the 00.

After some practice an assistant can punch the upper air cards at the rate of about 30 an hour. Types of cards used for recording commercial information usually have a simpler lay-out than the upper air cards and do not use all the 80 columns; a trained operator can punch these cards at the rate of about 150 cards an hour.

As errors are unlikely to be detected when the cards are being sorted and analysed mechanically the cards must be meticulously checked after punching either by " reading back " or using a " verifying punch ". Verifying punches are expensive and not at present used in meteorological offices. The cards are also tested for mechanical punching defects by placing them on a special gauge. Since any error necessitates punching a completely new card the greatest care has to be taken to ensure accuracy at the first attempt. The machines which sort and tabulate the cards necessarily work to very fine limits so that cards only slightly warped are liable to cause a jam. Great care has therefore to be exercised in storing and despatching cards to ensure they are not damaged.

The extraction of statistical data from the cards can best be illustrated by an example. Suppose the average relative humidity, extreme values and frequencies of 10 per cent. ranges are required for a certain station at the 500-mb. level for the midday ascent. There will be roughly 2,000 cards to be examined. The various sorting and tabulating machines operate on the same basic principle; the appropriate columns of a card are " scanned " by minute wire brushes

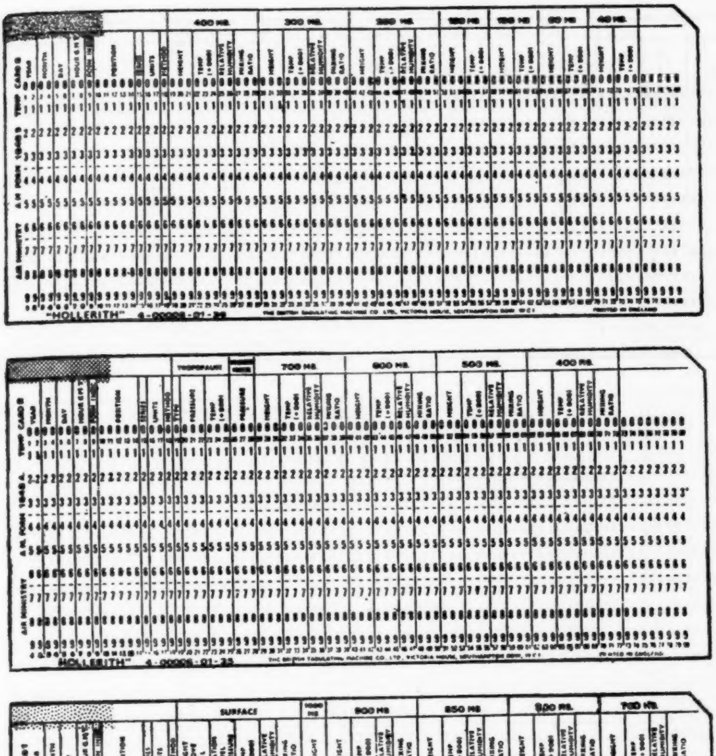


FIG. 1—UPPER AIR TEMPERATURE AND HUMIDITY HOLLERITH CARDS

and when a punch hole is found an electrical contact is made with a metal plate at the back of the card thereby operating the relevant mechanism.

To obtain the average humidity the cards would be run through a printer-tabulator machine after setting it to " scan " the columns giving humidity readings for 500 mb. This machine would give the total number of observations and the sum of these observations. If required, it also prints the individual values and their sum. This machine deals with the cards at the rate of roughly 80 a minute. Extreme values and frequencies would be obtained by using a counter-sorter machine which sorts the cards into compartments numbered

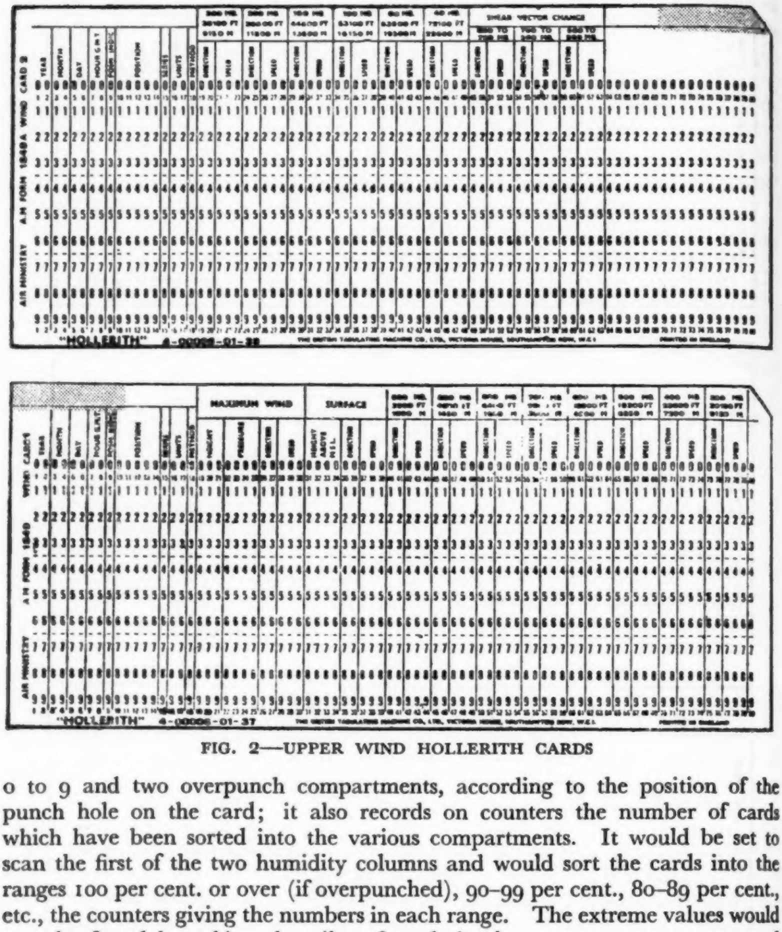


FIG. 2—UPPER WIND HOLLERITH CARDS

0 to 9 and two overpunch compartments, according to the position of the punch hole on the card; it also records on counters the number of cards which have been sorted into the various compartments. It would be set to scan the first of the two humidity columns and would sort the cards into the ranges 100 per cent. or over (if overpunched), 90–99 per cent., 80–89 per cent., etc., the counters giving the numbers in each range. The extreme values would next be found by taking the piles of cards in the ranges 0–9 per cent. and 100 per cent.* or over and putting them in turn through the machine with the sorter set to scan the second of the humidity columns. They would then be sorted into cases of 00, 01, 02,.... 101, 102, 103 per cent. and the extremes could then be picked out. The second sorting operation can, of course, be applied to the other ranges if more detailed information is required. This machine operates at a speed of about 350 cards a minute. Extraction of data, which would take an assistant hours of work, can thus be done almost in a matter of minutes using this system.

The applications mentioned in this note are comparatively simple; special machines have been produced for more complicated applications such as the production of employees' wage-slips after calculating and deducting P.A.Y.E. income tax.

*Values greater than 100 per cent. are sometimes recorded and the air is then said to be supersaturated.

MEAN PARTIAL THICKNESSES AT LARKHILL IN DIFFERENT AIR MASSES DURING WINTER

BY R. MURRAY, M.A.

In his paper "The temperature characteristics of different classes of air over the British Isles in winter"*, J. E. Belasco has tabulated the mean values of temperature at various heights. The purpose of this article is to draw attention to the probable mean values of the partial thicknesses 1000–700 mb. and 700–500 mb. relevant to Larkhill in winter (winter refers to the months December, January, February) in Belasco's air-mass classification. Belasco's work is then in a form more suitable for useful application to modern upper air analysis technique.

Belasco's air-mass classification.—The two fundamental air masses—polar and tropical—are subdivided into 12 types on the basis of trajectory and curvature of the surface currents (as given by the sea-level pressure chart).

Main type	Sub-type	Criteria
Tropical	T_1	Origin, Atlantic south of 40°N.; non-anticyclonic curvature.
	T_2	Origin, Atlantic south of 40°N.; anticyclonic curvature.
	T_3	Origin, Mediterranean or north Africa south of 40°N.
Polar	P_1	Direct polar outbreak from north; non-anticyclonic curvature.
	P_2	Direct polar outbreak from north; anticyclonic curvature.
	P_3	Approaching from north-west; non-anticyclonic curvature.
	P_4	Approaching from north-west; anticyclonic curvature.
	P_5	Approaching from west; non-anticyclonic curvature.
	P_6	Approaching from west; anticyclonic curvature.
	P_7	Approaching from south-west, after travelling south-east towards Azores.
	A_1	Siberian air from east; non-anticyclonic curvature.
	A_2	Siberian air from east; anticyclonic curvature.

Currents A_1, A_2 and T_3 travel mainly over land tracks.

Belasco's mean temperatures

(*a*) British Isles

Height	Air-mass types											
	T_1	T_2	T_3	P_1	P_2	P_3	P_4	P_5	P_6	P_7	A_1	A_2
ft.	*degrees Fahrenheit*											
20,000	−9·0	−5·3	−10·8	−44·7	−31·2	−41·6	−32·5	−34·3	−24·0	−24·4	−46·7	−26·8
15,000	9·8	14·1	8·8	−22·7	−10·9	−19·1	−12·9	−12·6	−3·9	−2·1	−26·6	−6·9
10,000	25·6	30·5	25·9	−2·5	5·6	1·5	4·7	7·6	14·9	16·3	−7·6	9·5
5,000	39·0	42·9	39·0	16·8	18·2	21·2	21·4	26·4	28·1	32·0	11·0	21·8
3,000	43·7	45·1	39·5	24·5	24·9	29·3	28·6	34·1	33·6	38·3	18·5	25·2
2,000	45·5	45·4	37·9	28·4	28·7	32·7	32·3	37·7	37·7	41·8	21·5	27·7
1,000	46·9	44·8	34·3	31·2	31·3	35·5	34·0	40·0	38·3	44·6	26·0	30·4
Surface†	50·5	47·3	39·3	33·9	33·9	39·7	36·9	43·5	41·0	47·1	29·9	33·9

†Mean surface temperatures at Kew.

Quart. J. R. met. Soc., London*, **71, 1945, p. 351.

(*b*) The mean values of temperature at upper levels of tropical and polar air in the Azores and Icelandic regions respectively are as follows :—

	Height (ft.)						
	20,000	15,000	10,000	5,000	3,000	2,000	1,000
T_A	−1·8	17·6	34·1	45·1	49·4	52·4	56·9
P_I	−56·9	−35·8	−15·6	4·6	14·7	19·2	23·9

T_A is northward-moving tropical current in Azores region.
P_I is southward-moving polar current in Iceland region.

Probable mean values of partial thicknesses at Larkhill.—Using Belasco's mean upper air temperatures for the British Isles and his mean surface temperatures at Kew together with the winter mean sea level pressure at Larkhill, the pressures corresponding to 1,000, 2,000, 3,000, 5,000, 10,000, 15,000 and 20,000 ft. in the different air masses were calculated. The various ascent curves were then plotted on tephigrams, thus enabling the partial thicknesses to be worked out. It is thought that values calculated in this way represent to a fairly high degree of approximation the mean partial thicknesses (in feet) at Larkhill in winter in the different classes of air. These values are tabulated below, together with estimates of the mean temperatures at 700 mb. (θ_7) and 500 mb. (θ_5).

	T_1	T_2	T_3	P_1	P_2	P_3	P_4	P_5	P_6	P_7	A_1	A_2
1000–700-mb. thickness (ft.)	9,460	9,520	9,420	9,070	9,110	9,140	9,160	9,250	9,280	9,350	8,970	9,150
θ_7 (°F.)	26	31	26	−1	7	3	6	9	15	16	−5	10
700–500-mb. thickness (ft.)	8,480	8,550	8,470	7,960	8,130	8,020	8,120	8,130	8,270	8,270	7,900	8,230
θ_5 (°F.)	−3	1	−4	−33	−22	−30	−23	−24	−16	−16	−36	−18

It should be noted that Belasco's mean surface temperatures for Kew have been taken as applicable to Larkhill in constructing the upper air ascents. This appears justified because (i) Larkhill is near to Kew, (ii) mean winter surface temperature at Larkhill differs by only about 1°F. from the Kew value and (iii) even a difference of several degrees between the Larkhill and Kew temperatures makes a negligible difference to the calculated partial thicknesses. As regards the surface pressure the mean winter value at Larkhill has been taken, though more accurate results would be obtained if the mean surface pressures in the different air masses were known. This uncertainty is unlikely to introduce an error of more than about 50 ft. in the values of the mean partial thicknesses tabulated above (the error is positive or negative according as the surface pressures are respectively less or greater than the mean winter surface pressure).

Mean partial thicknesses at main source regions.—Using Belasco's data the following values of partial thicknesses and 700-mb. and 500-mb. temperatures have been calculated.

	1000–700-mb. thickness	θ_7	700–500-mb. thickness	θ_5
	ft.	°F.	ft.	°F.
T_A	9,600	34	8,600	3
P_I	8,900	−11	7,780	−43

In the calculation of these values the surface temperatures at the Azores and Iceland have been estimated by extrapolation from Belasco's mean upper air data; for surface pressure the mean winter values for Lagens (Azores) and Reykjavik (Iceland) have been adopted.

Practical application.—Means of meteorological elements do not generally constitute a firm basis for forecasting, but the calculated mean partial thicknesses in different air masses should assist the upper air forecaster at least by preventing improbable forecasts of partial thicknesses over southern England during the winter months. It might even be that more positive help can be given. For instance, the partial thicknesses may be known at Lagens in the tropical air of a warm-sector depression which is moving towards the British Isles with a warm front likely to bring the tropical air over southern England. As a first approximation, the upper air analyst may assume that the Larkhill partial thicknesses in the warm air will be the appropriate mean values given above. If the known Lagens thicknesses differ much from the mean values given above, a second approximation can be made by adjusting the Larkhill means by a proportionate amount. A further adjustment can be made if the Larkhill surface pressure in the warm air is likely to be greatly different from the mean winter value (about 1015 mb.). The estimate thus made can then be compared with the forecast based on the advectional-empirical methods at present in use; if the values differ substantially some compromise may be indicated.

A note of warning must be sounded. Belasco's air-mass classification is reasonable and practical, but no classification can ever be entirely satisfactory: there must always be border-line cases or cases defying classification by virtue of cutting across whatever subdivision is adopted. Even so, a critical analysis will often enable the forecaster to make some allowance for this difficulty, say, by taking intermediate values between the means calculated in this note using Belasco's air-mass classification and data.

METEOROLOGICAL OFFICE DISCUSSION

The measurement of humidity

The discussion on March 28 took the form of a symposium on the measurement of atmospheric humidity and was opened by Dr. D. N. Harrison and Mr. J. R. Bibby.

Dr. Harrison began by pointing out the large range of variation of water-vapour pressure in the atmosphere. Between saturation at tropical surface temperatures and the very low relative humidities of the stratosphere, the ratio is about $10^7 : 1$.

The following quantities are commonly used to specify the humidity, or are given by the readings of instruments:—

1. (*a*) Vapour pressure, e
   (*b*) Dew (or frost) point, T_d
2. Vapour concentration (density), d_v
3. Relative humidity, U.

Adding to these

4. Temperature, T

and remembering that the dew or frost point is a function of the vapour pressure, so that these may be counted as one, we have four quantities, between which two physical relations exist ($d_v/U = f(T)$ and $d_v T/e$ = constant). Thus if any two are known the other two can be calculated. We always measure temperature, but humidity instruments measure various different things, and it is a matter of importance to the instrument designer to know what accuracy is required at different parts of the scale: for instance, do we want to know the relative humidity with the same " probable error " at high and low humidities and at high and low temperatures? or do we want the vapour concentration with a certain absolute error, or a certain percentage error?

Some of the chief methods of measuring humidity are shown in the table (after Middleton*) roughly in order of the time required to make an observation.

Method	Quantity measured	Remarks
A. Slow		
1. Total absorption (gravimetric, etc.)	Vapour concentration or pressure	Absolute method. The most accurate.
B. Intermediate (equilibrium, involving lag)		
2. Psychrometric	$e_{Tw} - e$	Inaccurate at low temperatures.
3. Absorption		
a. Change of dimensions (hair, gold-beaters' skin, etc.)	Relative humidity	Slow response at low temperatures; hysteresis.
b. Electrical resistance (lithium chloride, zinc chloride, ceramics)	Relative humidity	Capable of faster response than 3*a*. Temperature correction.
c. Film thickness by interference	Relative humidity	Fast response. Independent of temperature.
d. Dew-point recorder	Vapour pressure	Uses lithium-chloride solution.
4. Diffusion	Vapour pressure	
5. Condensation	Dew (frost) point	Suitable for low temperatures. Absolute method.
6. Thermal conductivity	Vapour concentration	
C. Miscellaneous		
7. Aircraft trails	Relative humidity	
8. Temperature rise on absorption of water vapour by cotton	Vapour pressure?	
D. Instantaneous		
9. Infra-red absorption	Total water content along path	Knowledge of absorption coefficients required.
10. Dielectric constant } Refractive index }	Vapour concentration	

Notes—Method 2 measures the difference between saturation pressure at wet-bulb temperature and existing vapour pressure.
Methods 3*a*, 3*b*, 3*c* require calibration.
Methods 2, 3*a* and 3*b* have been used in radio-sondes.

The first method is really an analysis. It consists in absorbing all the water vapour in a given sample of air and weighing it or measuring the change of pressure. It is an absolute method (that is, it does not depend on the properties of any substance or on the calibration of an instrument) and is very accurate, but too slow for meteorological purposes.

*MIDDLETON, W. E. K.; Meteorological instruments. Toronto, 2nd edn., 1943.

Next we have a group of methods (Nos. 2–6) in which a state of equilibrium has to be established and some factor in the equilibrium condition is a measure of the humidity. All these involve more or less lag, since the equilibrium takes a finite time to establish itself.

In the psychrometric method the equilibrium is thermodynamic.

Methods 3 *a*, *b* and *c* depend on the change in some property of a substance which absorbs moisture, and therefore involve calibration. The first group, consisting of hair, gold-beaters' skin and some other substances, responds by a change of dimensions. The primary controlling factor is relative humidity (below freezing point, the relative humidity with respect to water) but hair has also a temperature coefficient. Glückauf found that the calibration of gold-beaters' skin was independent of temperature over a wide range. These substances, being semi-crystalline in structure, suffer from serious hysteresis after exposure to low humidities, owing to internal strains set up by drying.

Group 3*b* consists of substances which respond by a change of electrical resistance. Instruments using lithium-chloride solution are now well known; they have a large temperature coefficient, and also polarise if direct current is used, but can be made faster in response than 3*a*. There are also ceramic substances, such as kaolin, whose resistance changes with humidity; these are not yet well understood.

The thickness of a hygroscopic film, of the order of one wave-length of light, has been measured by an interference method 3*c*, and this has been shown to provide a very rapid measurement of relative humidity, independent of temperature.

Another application of lithium chloride is in the dew-point recorder, which will be described later.

The diffusion hygrometer depends in principle on the difference between the rate of diffusion of air and of water vapour through a porous membrane.

The dew- or frost-point method is an important one because of its accuracy at low temperatures, because it is an absolute method, and because a sample of air can be subjected to variations of temperature without change in its dew (frost) point, provided that moisture is not added to or taken from it. The frost-point hygrometer will be described later.

The thermal conductivity of air depends on the amount of moisture present, and an instrument based on this principle has found industrial applications.

A theory has been worked out (No. 7) according to which the length and diameter of aircraft condensation trails could be used to give a measure of relative humidity, but has not been tried in practice.

It has been found that, if a mass of dry cotton be exposed to a humid atmosphere, its temperature rises as it absorbs moisture, probably owing to the release of the latent heat of vaporization. An instrument which works on this principle has been described (No. 8), but it appears to be little more than a curiosity.

All the methods described so far involve alteration of the composition of the air sampled. The remaining methods leave the sample unchanged and are also instantaneous.

Water vapour has strong absorption bands in the infra-red, and these may be used to measure the vapour concentration by observation of the absorption over a measured distance (No. 9). A knowledge of the absorption coefficients is required, and the situation is complicated by the fact that they depend on both the temperature and the total pressure. No doubt laboratory experiments will elucidate these matters.

Lastly, the dielectric constant and refractive index of air depend on the amount of moisture present, and are capable of measurement: for instance, by the variation in frequency of a resonant cavity containing the air.

Methods suitable for use in a radio-sonde were next considered. The requirements are:—

(i) The instrument must give a response of a type which can be telemetered,

(ii) It must be light, small in bulk, and cheap,

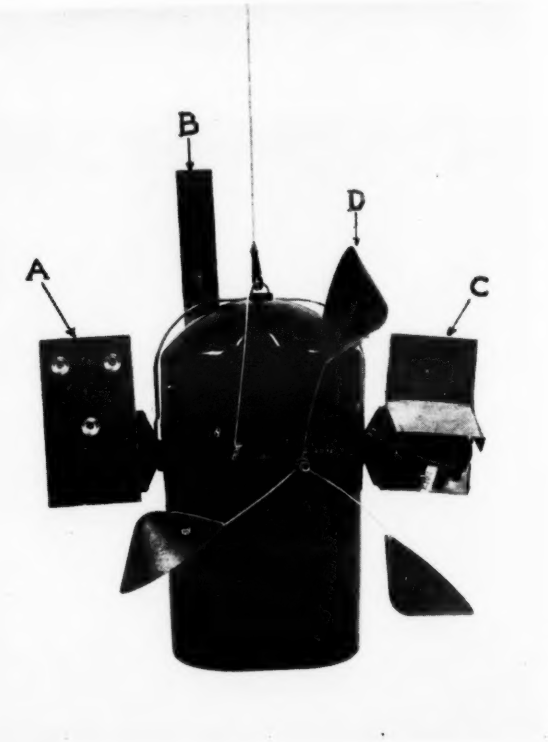
(iii) The response must be as rapid as possible, with a minimum of hysteresis, and the calibration stable.

Although gold-beaters' skin is the best of the substances in group 3*a*, the electrical-resistance types 3*b* offer a better prospect for future development, in respect of speed of response and absence of hysteresis. It is unfortunate that method 3*c* presents great difficulties in telemetering.

Mr. J. R. Bibby then described a number of hygrometers in greater detail, the first one being the Dobson-Brewer frost-point hygrometer. This instrument is noteworthy as having given the first accurate measurements of humidity in the high atmosphere and having led to the discovery (by Brewer in 1943) of the extreme dryness of the stratosphere. The instrument depends upon the deposition of frost from a jet of air upon the cooled surface of an aluminium thimble. In early models the observer controls the cooling so as to maintain a steady film, a process needing considerable practice. Later developments have made this easier, a photo-electric cell being used to detect the ice deposit. In the latest model, now under development, automatic control of the thimble temperature by the deposit itself ensures that the thimble is maintained continuously at the frost-point temperature. It was pointed out that this type of instrument is almost unrivalled among hygrometers in combining simplicity of theory with stability of calibration.

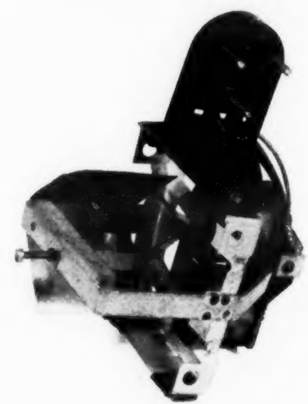
Mr. Bibby went on to describe two hygrometers which depend on the vapour pressure of a solution being lower than that of pure water. Lithium chloride is the usual solute. In the Gregory humidiometer a strip of cloth soaked in solution is wound on a metal frame to enable its electrical conductivity to be measured. Changes in relative humidity cause changes in the concentration of the solution and hence in its conductivity. A simple alternating-current circuit enables relative humidity to be indicated directly on a dial, or on a remote recording galvanometer. The scale is very non-linear, but elements can be made to have maximum sensitivity in any desired part of the range. This is an advantage for many industrial users, but a drawback for meteorological work. Other disadvantages are the need for temperature corrections, and the risk of lithium chloride being washed away by wet fog.

An American hygrometer using a somewhat similar element was then described. A higher potential (about 25 volts A.C.) is applied, and conduction



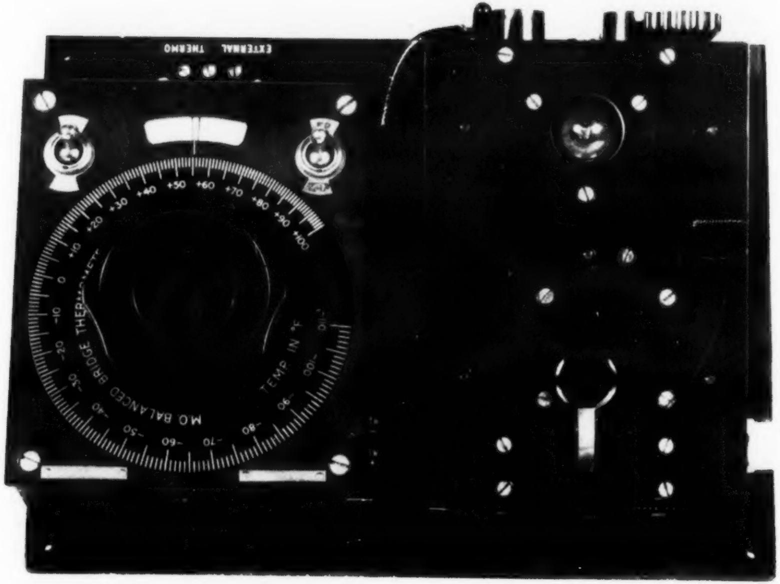
METEOROLOGICAL OFFICE RADIO-SONDE, MK. II

A = pressure element, B = temperature element, C = humidity element, D = windmill for the switching mechanism.



HUMIDITY ELEMENT OF THE RADIO-SONDE

The gold-beater's skin can be seen stretched out in line with the screw.

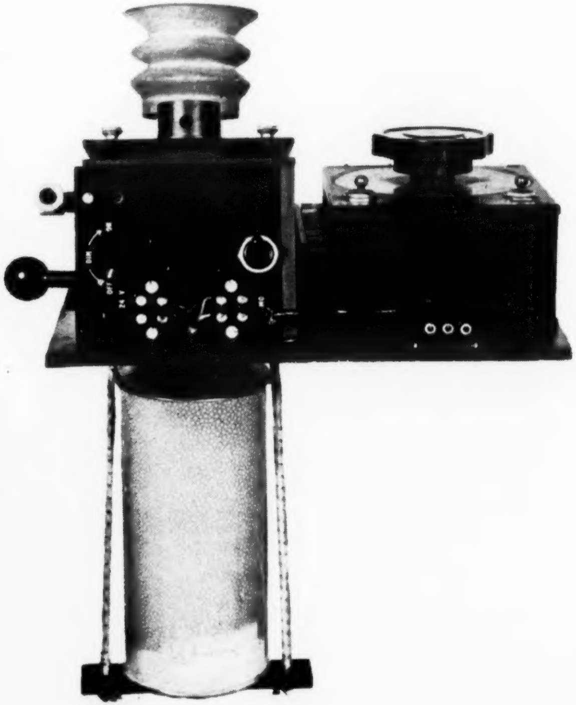


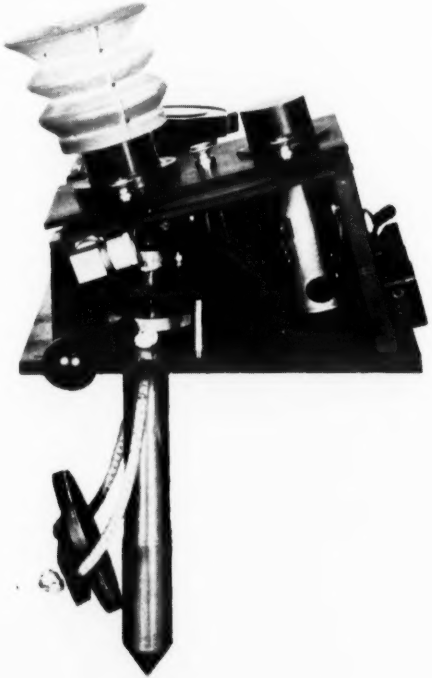
DOBSON-BREWER FROST-POINT HYGROMETER

The cover has been removed showing the elliptical mirror which concentrates the light from the small bulb at one focus on to the black surface of the thimble at the other focus. The balanced-bridge thermometer is on the left.

(See p. 172)

focus on to the black surface of the thimble at the other focus. The balanced-bridge thermometer is on the left.
(See p. 172)





DOBSON-BREWER FROST-POINT HYGROMETER

The left-hand photograph shows the complete instrument, the right-hand one the instrument from the side showing the pump containing the cooling fluid.

To face page 173]

HEAVY PRECIPITATION FROM A CUMULIFORM CLOUD OVER GEORGETOWN, MALAYA

(see p. 178)

PUMP AND THIMBLE OF THE DOBSON-BREWER HYGROMETER

The visible leads are connected to the two ends of the platinum-wire resistance by means of which the temperature of the thimble is measured.

through the lithium-chloride film causes its temperature to rise. This goes on until evaporation reduces the current flowing, and equilibrium is reached at such a temperature that the vapour pressure of the saturated solution equals the ambient vapour pressure. There is thus a constant relationship between the equilibrium temperature of the element and the vapour pressure (and hence the dew point) of the air. The element is wound on the bulb of a mercury-in-steel thermograph, and the recorder shows the dew point directly if a suitable scale is printed on the chart.

Mr. A. G. Matthewman, continuing the discussion, spoke from the point of view of the synoptic meteorologist. Psychrometric observations at the surface (from a Stevenson screen) and in the lower levels (from a captive balloon) are valuable, and radio-sonde readings are used up to the 700-mb. level, but in all cases there is an element of doubt how far a single observation or ascent is representative. Radio-sonde data are at present used in the form of dew points, but Mr. Matthewman considered that the wet-bulb potential temperature might prove preferable. Investigation was needed to discover whether increased accuracy of humidity measurement would be helpful or futile, having regard to the scale of the real variations in the atmosphere. For the forecasting of small-scale phenomena, *e.g.* cloud formation, the present standard of accuracy is probably not good enough. He thought that a device by which a radio-sonde could report the presence of cloud particles would be valuable.

Dr. G. D. Robinson expressed doubt whether psychrometric readings from a screen were satisfactory to the forecaster, and said he would like to have vapour concentration accurate within 1 per cent. On the basis of comparisons with radiation measurements he considered that radio-sonde humidity values were better than is often supposed.

Dr. F. J. Scrase pointed out that one of the advantages of the frost-point hygrometer was that the sensing element—the thimble—possesses a durable surface not easily damaged by a high rate of ventilation, an advantage not shared by hair, gold-beaters' skin or lithium-chloride film. He also suggested that it might be possible to make an instrument for measuring humidity on the cloud-chamber principle, in which condensation takes place in the air.

Dr. J. M. Stagg pointed out that in the resolutions of the I.M.O. Conference, 1947, relative humidity is defined in terms of mixing ratios instead of vapour pressures, and asked to which of these quantities substances such as gold-beaters' skin actually responded.

Mr. D. D. Clark described some of the difficulties of the frost-point hygrometer. At temperatures between freezing point and $-15°$C. it is difficult to be sure whether it is dew or frost that is formed, and, in this respect, each thimble surface has its own individuality which may change with use. At about $-80°$C. the deposit is formed as amorphous ice, which cannot be detected, owing to its glassy surface. Mr. Clark suggested that at low atmospheric pressures the accuracy of the psychrometric method might improve, owing to the factor p in the psychrometric equation.

Cdr. C. E. N. Frankcom described the difficulties of measuring humidity at sea.

Mr. C. J. M. Aanensen wanted an instrument suitable for use on fast aircraft.

Mr. O. M. Ashford thought it should be possible to state the accuracy required in synoptic meteorology. He stressed the importance of adequate ventilation

of psychrometers, saying that some clockwork Assmann psychrometers were defective in this respect. The new hand-operated psychrometer had been specially designed for use on board ship. He referred to the improvement in the performance of hairs treated by the Frankenberger process. With regard to Mr. Clark's suggestion, Mr. Ashford pointed out that at low pressures the lag of the psychrometer would become very large.

Mr. A. J. Drummond stressed the fact that serious errors could arise in the psychrometric method through the use of an incorrect constant, and said that satisfactory results had been obtained below freezing point by the use of saturated solutions of various salts.

Mr. P. M. Shaw described comparisons which he had made between psychrometric readings from a screen, an Assmann and a hand-operated psychrometer, and suggested that the psychrometric tables used for screen readings on land were not appropriate for a Bilham screen on board ship, where the ventilation is greater.

Mr. W. H. Hogg, discussing the use of the hand-operated psychrometer in microclimatology, said that the difficulty was to obtain air from the exact level desired without disturbance by the observer or contamination by air which had passed through the instrument.

Mr. Hickman (National Physical Laboratory) said, in reply to Mr. Hogg, that the best method would be to use long tubes to sample the air. He pointed out that the design of the Assmann psychrometer is faulty: the air flow should be at right angles to the thermometer bulbs. He suggested a psychrometer employing thermo-couples.

Dr. Harrison and *Mr. Bibby* replied briefly to the discussion. With reference to Dr. Scrase's suggestion, Dr. Harrison said he thought there would be difficulty in knowing the precise degree of supersaturation at which condensation took place. In reply to Dr. Stagg's question, the difference between the relative humidity defined in the two ways was so small that the matter could not be settled by experiment. Mr. Bibby thought that what the gold-beaters' skin responded to was the relative humidity as defined by the vapour pressure rather than by the mixing ratio.

OFFICIAL PUBLICATIONS

The following publications have recently been issued:—

PROFESSIONAL NOTES

No. 96—Cooling of air by rain as a factor in convection. By J. S. Sawyer, M.A.

The rain produced during convectional storms cools the air through which it falls, and the cooled air descends as its density is greater than that of the surrounding air. This is an important part of the process of convection. It may be responsible for the release of as much energy as is due to the buoyancy of upward currents; also the downward currents of cooled air may be deflected by hills and determine the later development and movement of a storm. Pressure may rise several millibars as the result of cooling of air by rain.

The most favourable conditions for the development of the phenomena occur in tropical regions on the borders of continents; similar but less intense effects are produced in temperate latitudes.

No. 97—*Some correlation coefficients between certain upper air data.* By Sir Gilbert T. Walker, C.S.I., F.R.S.

The author gives correlation coefficients and regression equations between ozone content, pressure at 0, 5, and 7 Km., temperature at 1, 5, and 7 Km. and the height of the tropopause. Some of the data over southern England are for the period January to September 1940 and some for June to October 1941.

The first aim was to determine if ozone was more closely related to subsequent pressure at 5 Km. and temperature at 7 Km. than with those elements for the same or previous days. This was found not to be the case.

The correlation coefficients found are in general agreement with those found by others. An attempt at a physical explanation of the coefficients is made based on a description by B. and E. Haurwitz* of pressure and temperature variations in cyclones. The temperature changes associated with the passage of isallobaric highs and lows as described in the Haurwitz paper agree well with the correlation coefficients except near the ground where they are in the opposite sense. The change near the ground is ascribed to the lack of recently formed cyclones over England.

One of the Haurwitz diagrams suggests it should be possible to predict the height of the tropopause from the surface pressure. The coefficients are found not to encourage this idea, and all that can be said is that when pressure changes are not too rapid the changes in surface pressure precede those of the height of the tropopause, but when pressure drops and recovers rapidly in 24 hours there is no suggestion of precedence in surface pressure.

The following publication will be issued shortly:—

GEOPHYSICAL MEMOIRS

No. 82—*Weather forecasting in tropical regions.* By A. G. Forsdyke, Ph.D., D.I.C.

This memoir consists mainly of a general commentary on the problem of weather forecasting in the tropics as it appeared in the later years of the second World War. It is based on the author's experience with the meteorological service in east Africa and the western Indian Ocean augmented for war purposes, together with the numerous notes and reports many of them unpublished, prepared by personnel of the meteorological services operating in tropical regions.

An introductory section outlines the uses made of weather forecasts in tropical countries. Then follow sections dealing with three main problems of tropical synoptic meteorology. First, the relation between wind and pressure distribution is considered from the point of view of modifications of the geostrophic-wind equation and other pressure-wind relations required in low latitudes. The special significance of convergence in the horizontal wind field is emphasised and a technique suggested for its calculation. Next follows a brief discussion of upper air temperature and humidity and convectional phenomena. A third section deals with the general principles of frontal analysis in the tropics having regard to the theoretical background as well as to forecasting and flying experience.

The memoir concludes with a list of problems for investigation suggested by the studies undertaken for its preparation.

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*HAURWITZ, B. and HAURWITZ, E.; Pressure and temperature variations in the free atmosphere over Boston. *Harvard met. Studies, Cambridge, Mass.* No. 3, 1939.

METEOROLOGICAL RESEARCH COMMITTEE

At the 57th meeting of the Meteorological Research Committee, held on March 23, the annual reports from the sub-committees were received and the revised programme of research for the forthcoming twelve months was approved.

Four members of the Committee were nominated to serve on a Gust Research Panel, which has been instituted, jointly with the Aeronautical Research Council, under the chairmanship of Sir Geoffrey Taylor.

ROYAL METEOROLOGICAL SOCIETY

The meeting of the Society held on March 16, 1949, with Mr. E. Gold, Vice-President, in the Chair, took the form of a discussion on agricultural meteorology. The discussion was opened by Dr. H. L. Penman and Dr. L. Broadbent of Rothamsted and by Mr. R. W. Gloyne of the Meteorological Office.

Dr. Penman dealt first with the general requirements of agriculturists for weather forecasts. These were forecasts for a year ahead for long-term crop planting strategy, for about 14 days for mobilising equipment to deal with plant diseases, and short-term ones for such matters as protection against frost. He then went on to discuss, as his main topic, the effects of incoming radiation on the evaporation of water from the soil and the transpiration of water from plants. He stated that in the long run around 90 per cent. of the energy of the incoming radiation was used up in providing energy for evaporation from soil and plants. Experiments were described showing that transpiration from plants amounted to about 75 per cent. of evaporation from a free-water surface under similar meteorological conditions. Finally, he described an experiment in controlled irrigation carried out in Surrey in 1948, in which the crops grown in areas irrigated according to instructions based on rainfall and temperature measured over a period, were compared with those on areas irrigated by the farmer in the usual way.

Dr. Broadbent described the effects of weather on potatoes in great detail. He dealt first with the effects of spring weather on the sowing of the seed potatoes and of summer weather on the development of the tuber. Cold weather in spring, delaying planting by a day, reduces the crop by about five per cent., while hot dry weather in late summer is very deleterious. The effects of weather on potatoes in the warmer parts of the British Isles are, however, mainly concerned with the transmission of virus diseases by aphides. These insects can only fly in winds of under 2 m.p.h. and they develop more quickly in hot weather. Dr. Broadbent gave much detailed information on this subject.

Mr. Gloyne, who had little time after other speakers had finished, dealt with the need for accurate weather forecasts for disseminating insecticides in dust or spray form, and with the use of climatological data in agricultural planning. On the first topic he pointed out that the distribution of the insecticides is much affected by wind, and that the dust needs something to stick to on the leaf surface, so that dew forecasts may be necessary. Applied climatology was of value in deciding whether a particular agricultural method could be used. Thus, haymaking by swath-curing needs three successive dry days, and the question arises as to how often such favourable sequences can be expected in any part of the country.

The general discussion which followed was a lively one. Among the points raised were the desirability for a forecast service for farmers as good as that now provided for aviators, the modification of general area forecasts to individual farms *e.g.* in connexion with frost, meteorological conditions for the growth of cotton in the Sudan, and the need for a detailed micro-climatological survey of the country to assist in deciding what areas should be used for new towns and what devoted to agriculture.

ROYAL ASTRONOMICAL SOCIETY

A meeting was held on January 28, 1949, to discuss river-flow survey and records, Sir Roger Hetherington being in the chair.

Mr. H. J. F. Gourley opened the discussion with a general account of the use of water for supply, both from reservoirs in the upland regions and from the main river. In the absence of river-flow records, estimates of the potentialities of any area had had to be based in most cases on rainfall records, but with the passing of the Rivers Boards Act 1948 the Minister of Health is given powers to direct a River Board to measure the flow of any river, stream or inland water in the area, as well as to record the rainfall.

Dr. J. Glasspoole dealt with the effect of the meteorological factors of rainfall and evaporation on the run-off. Where records of both annual values of rainfall and run-off are available, the correlation coefficient is usually of the order of $+\cdot 9$, but more records of run-off are necessary to define the variation of the loss (rainfall minus run-off) over the country. He thought that the greatest progress would be made by considering the whole hydrological cycle of rainfall, evaporation and run-off.

Capt. W. N. McClean gave an account of his own work in measuring the flow of Scottish rivers, especially in regard to the practical difficulties.

Mr. W. Allard, who had been concerned with publication of the *Surface Water Year Book of Great Britain* by the Ministry of Health and Scottish Office before the war, gave an account of what might be done as a result of the Rivers Board Act 1948 to define the flow, and enumerated some of the methods of expressing the results as set out in " Flood Estimation and Control " by B. D. Richards.

Mr. E. Gold referred to the accuracy which could be obtained by the scientific study of rainfall data and the importance of run-off records as a means of determining the evaporation. There were difficulties in measuring the evaporation directly because of the great variety of different types of surfaces involved. He also regarded as important the effect of the rain on different surfaces in changing the height of the stream. It is interesting to recall that Mr. E. Gold was Vice-Chairman of the British Association Research Committee which reported in 1933 on the Inland Water Survey in the British Isles.

Mr. R. V. Stock, Chief Engineer to the Thames Conservancy Board, referred to the long series of run-off records available since 1883 for the Thames Valley draining to Teddington, which had been summarised in various publications, and to proposals to construct two additional weirs for the measurement of the flow further up stream.

Further discussion dealt mainly with the accuracy of the measurement of river flow by various methods, details being given by Sir Claude Ingles.

LETTERS TO THE EDITOR

Formation of rain

The top photograph facing p. 173 is submitted in response to Mr. Best's letter published in your issue of October 1948. It was taken at Butterworth, Malaya, looking towards Penang Island, at 1335 on May 2, 1947, and shows a cumuliform cloud giving heavy precipitation over and behind Georgetown. While there is no instrumental evidence, there is good reason for thinking that this precipitation originated at temperatures above 0°C.

The height of the cloud top can be calculated from the estimated distance of the cloud and the size of the photographic image and can be shown not to exceed 12,000 ft. A freezing level below this is hardly compatible, in moist conditions, with the surface temperatures exceeding 80°F. which regularly occur in Malaya during the afternoon. Indeed, at that time of the year a freezing level of 15,000–17,000 ft. would usually be forecast.

There is no doubt that the rain falling on the town originated in the cloud in question as at that time there was in that direction no higher cloud formation in which it could have originated.

Other cumulus towers in the vicinity, giving precipitation of which traces appear in the upper part of the photograph, were much higher than the cloud here shown, and showed signs of ice formation in their upper parts.

J. M. CRADDOCK

January 17, 1949

Structure of a fast-moving cold front

On the morning of October 21, 1948, an aircraft of Trans-Canada Airlines flying across the Atlantic on the great circle from Goose Bay to London Airport, made an interesting report on a fast-moving cold front, encountered about 0600 G.M.T.

At this time a depression of depth 985 mb. was centred at 59°N. 37°W. moving east-north-east at 35 kt. A cold front extending southwards from the centre was moving eastwards at about 40 kt. The warm air ahead of the front was tropical air ; the cold air behind, polar air from the Canadian arctic.

Flying at 15,000 ft., on a track at right angles to the front, the pilot reported an increase of temperature from −24°C. to −11°C. at about 45°W. This change took place in 10 minutes, in clear air, and was accompanied by moderate turbulence. The aircraft continued in clear air for a further 150 miles. It then entered cloud with moderate to heavy icing, and these conditions persisted for another 100 miles.

This is an excellent illustration of the standard type of fast-moving cold front. Text-books state that the frontal cloud of fast-moving cold fronts rises vertically above the base of the front. They also state that if the component of wind velocity perpendicular to the front increases with height, then warm air will descend the frontal slope, and it follows that there will be clear air above the frontal surface. Both these features are clearly illustrated by the pilot's report, the temperature discontinuity and turbulence indicating the position of the frontal surface at 15,000 ft., and the cloud indicating the position of the surface front. The 500-mb. chart showed that the thermal wind between 1000 and

500 mb. was 70 kt. at an angle of 25° to the front ; this was equivalent to an increase in the wind component at right angles to the front of 30 kt. in 18,000 ft. Moreover the approximate slope of the front was somewhere between 1/50 and 1/90 which is in good agreement with the average figure generally quoted.

F. A. SHARP
S. E. VIRGO

London Airport, February 17, 1949

NOTES AND NEWS

Supply of meteorological information to power and transport authorities

The Meteorological Office has for many years provided weather forecasts and warnings to public utility companies. During the past eighteen months there has been a considerable increase in these arrangements and this note gives a brief survey of the more important of them as they stand at present.

British Electricity Authority.—Forecasts are supplied to the National Control Centre by the Central Forecast Office and to the seven local Grid Control Centres by the nearest Type I forecast office. The National Centre receives at 6 a.m. daily a forecast of the temperature and wind and weather expected between 4 p.m. and 6 p.m. over England and at 6 p.m. similar information relating to 8 a.m. next day. A synoptic chart of the weather at 0600 G.M.T. is also sent daily from Victory House to the National Centre. The local Grid Control Centres receive forecasts five times daily of the temperature weather and wind over the areas they control. The last one, at 8 p.m., refers to the anticipated weather for 8 to 9 a.m. next day, the remainder are forecasts for up to 5 hours. Further outlooks for 12 hours accompany the forecasts.

A meteorological officer is attached to the Headquarters of the Authority to investigate the meteorological problems associated with electricity distribution, and to interpret the forecasts to meet the authority's requirements.

Gas Companies.—Gas Companies receive warnings of weather, such as cold, fog, or snow, which leads to a heavy public demand for gas. Warnings are issued under thirteen heads such as " Onset of cold or hot weather within next day or two ", "substantial fall or rise of temperature within next 24 hours", " severe night frost with day temperature above freezing point ", "temperature expected to remain below freezing day and night ", " snow expected in substantial amount ", " prolonged cold or hot spell ", " thick or dense fog tomorrow ", etc. Warnings are prepared by the Central Forecast Office and, prefixed by the words GASCO WARNING, are broadcast by teleprinter. Each gas company is looked after by an allotted meteorological office which distributes the warnings as they are received.

Ministry of Fuel and Power.—During winter months forecasts of the anticipated temperature on Saturday and Sunday are supplied to Regional officers of the Ministry of Fuel and Power. The forecasts are compiled by the Central Forecast Office and distributed by local meteorological offices.

British Railways.—Railway operations are seriously affected by fog, snow, frost, glazed frost and gales. Fog affects railways if visibility falls below 200 yd., and fog-working arrangements, for which special staff have to be deployed, are

then necessary. Snow is most serious when drifted into deep banks but may clog points without being very deep. Frost affects points, water troughs etc., while glazed frost causes lack of adhesion, and clogs points. Both snow and glazed frost are particularly serious on electric railways as they form an insulating layer on the conductor rail.

Warnings of the onset of these phenomena are prepared by Type I stations and supplied to the railway control officers allocated to them. Close liaison is maintained between the railway controllers and their meteorological advisers. The railway authorities send reports of current weather on their tracks as necessary, and forecasters have visited sections of track known to be particularly subject to weather troubles. The railway authorities keep their meteorological advisers on their toes by sending them weekly returns of the value of the warnings.

Shipping.—Arrangements have been made for masters of merchant ships, ship-owners and these concerned in the movements of shipping or cargo to obtain local weather forecasts from the forecast centres nearest to the main ports in Great Britain. To each main port is allocated a forecast centre. News of the service has been promulgated in *Notices to Mariners* and through Port Meteorological Officers and Merchant Navy Agents.

Snow clearance.—To enable Local Authorities to mobilise the labour and equipment necessary to keep the main traffic routes clear of snow, warnings are issued to County Surveyors, City Surveyors, and the Divisional Road Engineers of the Ministry of Transport.

Warnings of snow, with special mention of drifting, are compiled at the Central Forecast Office, broadcast by teleprinter, and telephoned by local meteorological offices to the Surveyors, etc.

Royal Automobile Club.—Forecasts and reports are supplied in winter to the Royal Automobile Club Touring Department and to local offices of the club. The information consists of forecasts of coming weather with statements of reporting stations with visibility less than 500 yd., or at which snow or sleet is falling, or with glazed roads, or where more than 20 mm. of rain has fallen in twelve hours. The messages are sent twice daily, at 10 a.m. and 3 p.m.

OBITUARY

The Right Hon. Viscount Ullswater, G.C.B., one of the outstanding Speakers of the House of Commons, who died on March 27, aged 93, was much interested in rainfall recording. Since 1912 he had caused an annual return of the observations at Campsea Ashe, near Woodbridge, Suffolk, to be sent for use in compiling the annual volumes of *British Rainfall*.

NEWS IN BRIEF

The Meteorological Office football team beat Air Ministry Accounts by four goals to nil in the final of the Air Ministry Football Cup at Northolt on April 12, 1949. This is the eighth occasion on which the Meteorological Office team has won the competition, and the second time in three successive seasons.

The football team of the Central Forecasting Office, Dunstable, won the Dunstable Benevolent Hospital Charity Cup on April 28, 1949, when they beat Totternhoe by two goals to nil in the final.

REVIEWS

The behaviour of barometric pressure during and after solar particle invasions and solar ultraviolet invasions. By B. Duell and G. Duell. *Smithson. misc. Coll.*, **110**, No. 8. 8vo. 9½ in. × 6¼ in. pp. ii+34. Smithsonian Institution, Washington, D.C. 1948.

Investigations of the influence of solar activity on weather have hitherto been mainly confined to the variation of the solar constant and sunspot numbers, and their correlation more especially with long-period weather changes. It is well known that the results so far obtained in this field are disappointing, the correlation coefficients being small, and their implications uncertain.

In this paper an attempt is made to relate atmospheric pressure with certain solar phenomena, namely solar particle and ultra-violet invasions, which are observed through their terrestrial effects and give some indication of solar activity. Since, until recently, solar particle invasions had not been directly observed, variations of the earth's magnetism, with which they are closely associated, have been used instead. The investigation is limited to daily values of the correlated phenomena.

Since the solar phenomena are generated by eruptive processes in the sun, they select certain key days of especially high solar activity. In the investigation, sets of key days have been determined from records of magnetic disturbance over the period 1906–37. The mean anomaly of sea-level pressure for each of a number of stations in Europe is calculated separately for the key days and each of the few preceding and following days, and graphed against time (the "superposed-epoch" procedure). Only for the winter months of the years near sunspot minima are the curves in any way remarkable, but then they show striking similarities. Some three days after the key day, in a disturbed period, the pressure falls to a well defined minimum, while in a quiet period it rises to a maximum after a similar interval, the average difference between maximum and minimum amounting to about 3 mb.

These results are in themselves very interesting, but their significance seems to lie in the geographical distribution of the pressure anomalies. The anomaly reaches its greatest negative value over Europe simultaneously with its greatest maximum value in the Iceland region, so that the normal pressure difference between these areas is reduced by some 5 mb. and the mean circulation must be affected accordingly.

For the ultra-violet invasions the investigation covers only the period 1936–41, but the results apply to all months. They are presented in much the same way as for particle invasions, and are equally striking. For stations in Europe, sea-level pressure falls somewhat for one or two days after the key day, but reaches a pronounced maximum on about the third to fifth day. There is also some effect on the topography of the 500-mb. surface, which, on the day after key day appears to undergo a lowering of some 120 ft. over western Europe, while a rise of similar amount takes place in the Baltic area.

In so far as the particle and ultra-violet invasions may be predicted over the period of a few days between the appearance of the eruptive areas on the sun's limb and the time, depending on the solar revolution, when they may be expected to have terrestrial effects, these occurrences have a possible forecasting value. Moreover, the eruptions sometimes persist through a number of

solar revolutions. The effects on the weather, if any, have still to be worked out.

Numerous physical explanations of the effects are suggested, but none of them go beyond the stage of conjecture. Neither is any statistical test applied, so that it is not possible to judge the reality of the effects, but the evidence appears convincing.

Apart from its general interest the paper points a way to further investigations in the fields of atmospheric physics and statistical and synoptic meteorology.

A. G. FORSDYKE

Grundprobleme der Physik des Gewitters. By H. Wichmann. *Phys. Forsch.*, 1, Heft 1, 8vo. $8\frac{1}{4}$ in. × $5\frac{3}{4}$ in. pp. 118. Wolfenbütteler Verlagsanstalt, G.m.b.H., Wolfenbüttel und Hanover, 1948. Price : *DM.* 8.

The publishers noted in the title have instituted a new series of publications entitled *Physikalische Forschung* of which the small book under review forms the first number. The series is to provide a medium of publication for research papers too long for scientific journals and is edited by the well known physicist, Dr. Pascual Jordan. According to a list of future numbers six of the ten numbers in the first two volumes are to deal with geophysical subjects including the dynamics of cyclones and the theory of seismic waves. The first number is in paper covers. It is well printed with clear figures. There is no index. We wish every success to the new series.

The main object of this book seems to be to develop a theory of the production of thunderstorm electricity due to Lange, Findeisen and Wichmann which has not yet attracted much attention outside Germany. It was first published in a series of papers in the *Meteorologische Zeitschrift* in 1940 and 1943. The experimental basis of the theory is that an insulated conductor in a stream of air becomes positively charged when rime forms upon it, negatively charged when rime evaporates, and strongly positively charged when supercooled water droplets freeze upon it. In the first and third cases the small ice splinters torn away by the air stream carry a negative charge but what happens to the positive charge in the second case is obscure. These phenomena are ascribed by Lange to contact potential differences between the different phases of water. The main separation of charge in the cloud is then ascribed to gravitational separation of the small ice splinters and the heavy hailstones with assistance from the Wilson process which is supposed to apply to ice particles. By suitable assumptions about the vertical currents these processes are made to give a distribution of charge agreeing with the Kew alti-electrograph records of Simpson, Scrase and Robinson. The breaking-drop process is supposed to contribute a small effect at temperatures above the freezing point, but no use is made of the frictional electrification produced by clashing of ice particles which is invoked by Simpson and Scrase.

The assumptions on the vertical currents are supported by a good deal of information gathered during flights by gliders in thunderstorms at the Rhon glider meeting in 1938. These flights provided much interesting information on the vertical currents, hail and icing in thunderclouds. The vertical currents, referred to as " chimneys " from their shape, were smooth in the centre but turbulent on their edges. Large clouds contained more than one " chimney". Hail, encountered up to heights of over 8 Km., increased in size and weight with height and was very destructive.

Other sections of the book deal with the propagation of the lightning discharge following Toepler's theory, the electric field of thunderclouds and the electric field charges produced by lightning strokes.

A final chapter deals on normal lines with atmospherics and the maintenance of the earth's electric charge.

G. A. BULL

The formation and the development of occluding cyclones : a study of surface weather maps. By K. R. Postma. *Meded. Verh. Ned. met. Inst., De Bilt,* Serie B, **1**, Nr. 10. 4to. 12½ in. × 9 in. pp. iv+57, *Illus.* Staatsdrukkerij-en Uitgeverijbedrijf, The Hague, 1948, Price : 5 *florins.*

This is a paper on the kinematics of fronts and depressions.

In the course of his researches from 1938 onwards the author found, as others had already done, that there are substantial differences between the fronts on the published charts of European meteorological services, and that often no evidence could be found in the autographic records or observations of stations for fronts which according to the published charts (the Dutch, Bergen and Deutsche Seewarte are specifically mentioned) had passed over them.

He strongly attacks the drawing for " historical " or conventional reasons of fronts in positions for which there are no clear observations. He is particularly concerned with the conventional Norwegian assumption that the occlusion passes through the centre of the associated depression and that the " crest " of the so called wave depression is necessarily a low-pressure centre.

Taking the occluded depression, he gives a detailed kinematical study, based on gradient wind trajectories, of the displacement of a front initially extending out from the centre of a moving depression, and shows that the front would within a very few hours no longer pass through the centre and that the twisting effect is so great near the centre as to make recognition of fronts impossible. He also argues against the possibility of the centre being on the occlusion from the fact that at a station north-east of the centre of an eastward moving depression and in the loop of the occlusion the wind at the second passage of the front would back and not veer. As a corollary to this there follows the non-existence of the back-bent occlusion.

He next considers the formation of a warm sector in an initially straight front, and shows that if there is a fall of surface pressure due to high level disturbance on or to the north of the front the consequent air motion will lead to a bulge in the front which, opposed to the normal theory, is a consequence and not the cause of the fall of pressure. Detailed diagrams based on gradient wind trajectories and circular isobars as before are drawn to show the movement of the front. If the fall of pressure moves rapidly parallel to the front the bulge in the front travels rapidly along with the fall of pressure as an open " wave ", the so-called stable wave ; otherwise the motion corresponds to the so-called unstable occluding type. The effects of departure of the wind from the gradient value are not considered. A very good example of the rapid motion of a shallow wave on a quasi-stationary front, from the Atlantic to central Europe on February 3–4, 1948, is given, illustrated with seven charts. On this occasion a marked trough of low pressure well to the north of the front moved eastwards with the wave which, from the detailed observations plotted, at no time had a closed isobar at the crest.

The Atlantic charts for the period of the international swell observations, November 13–18, 1938, are also given, analysed at the time according to

conventional Norwegian methods, and re-analysed by the author, with no fronts passing through the low-pressure centres. Observations are given only on the re-analysed charts. Comparison would have been facilitated if they had also been given on the original " Norwegian " ones.

The paper does not throw much light on the physics of depressions but is certainly worthy of study by synoptic meteorologists.

G. A. BULL

Rockets and space travel. By Willy Ley. 16 mo. 8 in. × 5¼ in. pp. viii + 374, *Illus.* Chapman & Hall, Ltd., London. 1949. Price : 18*s.* 0*d.*

This is a popular book by a German rocket pioneer for those who are interested in rockets as such.

Much of the book is devoted to the history of the development of rockets from Chinese fireworks to the V2.

One chapter is devoted to a proposal for a meteorological rocket. This rocket is of the liquid-fuel type with a combustion chamber at the nose and the fuel tanks behind with a weight of 100 lb. and length of 10 ft. The purpose of the rocket is to carry radio-sondes rapidly up to any pre-set height from which they would drift down with the silent rocket by parachute, telemetering observations all the while. Such a device could be imagined for use over a desert, but could not be used over inhabited country. If rockets are ever used for routine meteorological ascents, the expendable powder rocket is more likely to be used than the complicated and expensive liquid-fuel rocket.

D. D. CLARK

WEATHER OF APRIL 1949

During the first week deep depressions were centred not far to the west and north of the British Isles, and one passed eastwards across the British Isles between the 5th and 6th. This was followed by an anticyclone, which drifted away to the continent on the 10th. During the rest of the month depressions mostly kept well to the north and north-west of Scotland, and anticyclones often extended north-eastwards from the Azores to cover the southern parts of England and Ireland.

Mean pressure for the month was about 1020 mb. over southern Europe and 1000 mb. near the east coast of Greenland. It was mostly between 1010 mb. and 1020 mb. in North America, where it differed little from the normal. In southern Europe it was between 5 and 10 mb. above the normal, and east of Greenland between 10 and 15 mb. below normal.

The weather over the British Isles was warm generally; it was very sunny in eastern and central districts but excessively wet in the mountainous districts of the western Highlands, the Lake District and Wales.

The first ten days of the month were very unsettled with widespread gales on the 3rd, 4th, and 7th. From the 1st to 5th troughs of low pressure associated with Atlantic depressions moved north-east over the country giving rain, which was heavy locally at times, particularly on the 3rd and 5th (4·10 in. at Borrowdale and 3·85 in. at Thirlmere, Cumberland, on the 3rd and 2·91 in. at Rhondda Water Works and 2·40 in. at Treherbert, Glamorgan, on the 5th). On the 5th and 6th a depression moved rapidly across south Ireland and northern England to the southern Baltic and on the 6th and 7th another moved rapidly across England to south Sweden. Rain, heavy in places, fell generally on the 6th, while wintry showers occurred on the 7th, with thunder

locally in the west Midlands. Rather widespread gales were recorded in England and north-west Ireland on the 7th. In the rear of the latter depression a polar air stream flowed over the British Isles and temperature fell considerably. From the 8th to 10th an anticyclone off our northly-west coasts moved rather quickly south-east and a short period of mainly fair weather prevailed, though rain was renewed in the west and north by the evening of the 9th, and on the 10th a cold front off the west coast of Ireland moving north-east caused considerable rainfall locally in the west and north-west. During the ensuing days pressure was low to the north and high to the south of the British Isles and a westerly type of weather prevailed with rain in the west but little or none in east Britain.

On the 14th and 15th an anticyclone over France moved north-east, while troughs of low pressure approached our western seaboard. Our air supply was drawn from the south, temperature rose considerably and fair weather prevailed over much of the country except Ireland and west and north Scotland. By the 15th, day temperature was unusually high for the time of year in some western districts and on the 16th, Easter Saturday, in eastern districts. The maximum temperature on the 16th reached 84°F. at Greenwich and 85°F. at Camden Square; the Greenwich figure was the highest in April since records began in 1841. Thunderstorms occurred locally in north-east England on the night of the 16–17th. During the following days temperature was lower but still much above the average in most districts. Over a substantial area in the south-east the Easter period was the warmest and probably the sunniest on record. On the 18th a weak trough of low pressure moving north-east brought slight rain to the northern half of the country, while on the 19th a trough moving south-east caused some rain, mainly slight, in the west and north. Meanwhile fair weather continued in the south. On the 20th and 21st a depression moved from mid-Atlantic to a position west of Scotland and thence to the North Sea; rain fell generally though not until the night of the 20–21st in England and Wales, where sunshine was abundant on the 20th. On the 22nd a trough of low pressure moving quickly east over Scotland was associated with heavy rain in Argyllshire and Inverness-shire (2·70 in. at Ardgour House, 2·80 in. at Loch Quoich and 2·60 in. at Fort William).

During the remainder of the month unsettled weather prevailed with depressions moving north-east or east to the north of the British Isles and associated troughs crossing the country. Gales were recorded in the north of Scotland on the 27th and 28th and rain or showers occurred at times, but there were also considerable amounts of bright sunshine. Thunder was recorded locally on the 25th.

The general character of the weather is shown by the following provisional figures:—

	Air Temperature			Rainfall		Sunshine	
	High-est	Low-est	Difference from average daily mean	Per-centage of average	No. of days difference from average	Per-centage of average	Per-centage of possible duration
	°F.	°F.	°F.	%		%	%
England and Wales	85	25	+4·3	120	−1	114	41
Scotland	75	26	+3·2	149	+4	97	32
Northern Ireland..	65	27	+3·6	118	+2	90	32

CLIMATOLOGICAL TABLE FOR THE BRITISH COMMONWEALTH, DECEMBER 1948

STATIONS	PRESSURE: Mean of day M.S.L.	PRESSURE: Diff. from normal	TEMPERATURES: Absolute: Max.	TEMPERATURES: Absolute: Min.	TEMPERATURES: Mean values: Max.	TEMPERATURES: Mean values: Min.	TEMPERATURES: Mean values: ½ Max. and Min.	TEMPERATURES: Mean values: Diff. from normal	TEMPERATURES: Mean values: Wet bulb	RELATIVE HUMIDITY	MEAN CLOUD AMOUNT	PRECIPITATION: Total	PRECIPITATION: Diff. from normal	PRECIPITATION: Days	BRIGHT SUNSHINE: Daily mean	BRIGHT SUNSHINE: Percentage of possible
	mb.	mb.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	%	tenths	in.	in.		hr.	%
London, Kew Observatory	1017·8	+5·2	56	22	48·0	39·6	43·8	+2·3	41·7	86	7·2	2·02	−0·27	17	1·4	18
Gibraltar	1021·1	+0·8	72	48	63·6	55·5	59·5	+3·5	56·6	89	7·7	5·77	—	16	3·6	37
Malta	1021·7	+5·5	66	46	61·6	51·6	56·6	−1·3	55·6	83	6·3	7·42	—	17	4·5	46
St. Helena	1015·1	−0·7	73	56	68·8	57·6	63·2	+2·3	57·9	95	9·5	0·97	−0·85	8	—	—
Lungi, Sierra Leone	1011·3	—	91	62	87·0	71·3	79·1	—	72·7	88	5·3	0·13	—	2	—	*
Lagos, Nigeria ..	1010·5	0·0	94	68	91·2	70·4	80·8	−1·0	76·7	89	7·8	0·00	—	0	5·7	49
Kaduna, Nigeria ..	1011·1	—	93	55	87·9	57·9	72·9	−1·4	54·2	19	3·1	0·00	0·00	0	8·9	77
Chileka, Nyasaland	1012·6	0·0	94	61	87·7	68·1	77·9	+1·8	67·6	63	5·8	1·86	−3·86	6	6·8	52
Lusaka, Rhodesia ..	1010·5	0·0	91	58	84·4	62·8	73·6	+1·8	64·2	65	6·5	2·68	−3·76	9	5·2	40
Salisbury, Rhodesia	1011·4	−0·1	88	49	82·4	59·6	71·0	+1·6	60·2	54	4·4	2·23	−4·87	11	5·9	45
Cape Town	1015·6	+1·3	83	47	76·7	59·7	68·2	+0·3	58·8	60	4·1	0·62	−0·19	5	—	—
Germiston, South Africa	1010·2	−1·9	92	46	83·1	58·7	70·9	+3·8	57·1	46	3·0	0·73	−4·05	6	9·7	72
Mauritius																
Calcutta, Alipore Obsy.	1015·2	−0·4	84	53	78·3	57·3	67·8	+1·3	59·7	82	0·8	0·00	−0·24	0	9·5	88
Bombay	1012·8	−0·7	91	67	87·3	70·5	78·9	+1·5	67·0	72	1·7	0·00	−0·05	0	9·8	90
Madras	1013·0	−0·5	86	66	82·5	69·7	76·1	−0·6	69·8	84	6·1	1·70	−3·65	8	7·3	65
Colombo, Ceylon ..	1010·4	+0·1	90	70	85·7	72·6	79·1	−0·4	72·7	90	6·7	5·22	+0·10	15	5·3	45
Singapore	1009·8	+0·1	93	72	87·6	74·0	80·8	+0·9	75·6	83	7·1	13·58	+3·02	17	—	—
Hongkong	1012·9	−6·8	80	58	71·9	63·2	67·5	+4·5	63·3	83	—	0·80	−0·23	8	4·2	39
Sydney, N.S.W. ..	1012·8	+0·9	95	57	75·9	62·7	69·3	−0·8	63·6	66	6·3	3·77	+0·91	9	8·3	58
Melbourne	1012·1	−0·6	98	44	78·1	53·9	66·0	+1·2	57·2	53	7·7	1·72	−0·55	11	5·6	38
Adelaide	1013·6	+0·3	99	48	78·7	57·8	68·3	−2·8	57·5	41	7·7	1·09	+0·06	5	7·6	53
Perth, W. Australia	1013·9	+0·7	94	50	77·7	58·6	68·1	−2·7	60·1	55	3·0	0·67	+0·11	4	10·0	70
Coolgardie																
Brisbane	1014·0	+2·0	90	65	83·4	68·3	75·9	−0·5	68·9	69	6·3	3·21	−1·68	11	8·0	58
Hobart, Tasmania	1007·5	−2·2	91	40	69·2	49·7	59·5	−0·7	52·3	52	5·8	1·84	−0·15	18	8·0	52
Wellington, N.Z. ..																
Suva, Fiji	1007·1	−1·5	85	67	81·3	73·5	77·4	−1·6	74·0	84	8·6	15·74	+3·22	26	4·2	32
Apia, Samoa ..	1006·7	−1·2	88	71	85·1	74·1	79·6	−0·4	77·7	86	8·5	32·92	+18·90	25	5·1	40
Kingston, Jamaica	1014·7	+0·7	92	67	88·2	70·4	79·3	+1·6	68·7	86	2·3	0·32	−1·27	6	8·6	77
Grenada, W. Indies	—	—	85	70	84·0	74·8	79·4	+1·2	74·2	78	8·4	2·28	−4·92	22	—	—
Toronto	1017·3	−0·3	52	−1	37·4	25·7	31·5	+4·4	27·0	75	8·8	2·12	−0·35	13	2·5	28
Winnipeg	1016·5	−2·2	37	−27	14·4	−2·2	6·1	+0·3	4·0	85	6·9	1·63	+0·69	11	2·6	32
St. John, N.B. ..	1015·1	+1·1	51	3	35·8	22·6	29·2	+4·8	24·7	85	6·4	4·20	+0·03	13	4·2	48
Victoria, B.C. ..	1013·5	−3·2	51	20	41·2	30·4	35·8	−5·3	33·1	88	7·5	6·30	+0·56	23	2·1	25

CLIMATOLOGICAL TABLE FOR THE BRITISH COMMONWEALTH, YEAR 1948

Stations	Pressure: Mean of day M.S.L.	Pressure: Diff. from normal	Temperatures: Absolute Max.	Temperatures: Absolute Min.	Temperatures: Mean values Max.	Temperatures: Mean values Min.	Temperatures: Mean values ½ Max. and Min.	Temperatures: Mean values Diff. from normal	Temperatures: Mean values Wet bulb	Relative humidity	Mean cloud amount	Precipitation: Total	Precipitation: Diff. from normal	Precipitation: Days	Bright Sunshine: Daily mean	Bright Sunshine: Percentage of possible
	mb.	mb.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	%	tenths	in.	in.		hr.	%
London, Kew Observatory	1016.3	+1.4	93	22	58.0	45.0	51.5	+1.1	47.8	80	7.2	21.45	−2.35	145	4.2	32
Gibraltar	1018.7	+0.8	95	42	72.0	60.2	66.1	+1.9	61.6	82	5.2	25.33	—	84	7.7	64
Malta	1017.2	+1.8	96	44	71.4	59.0	65.2	−0.9	62.2	71	4.4	23.17	—	76	8.7	72
St. Helena	1016.7	−0.4	81	52	67.3	57.7	62.5	+1.5	57.8	94	9.0	32.86	+1.22	178	—	—
Lungi, Sierra Leone	1012.1	—	94	62	84.3	73.9	79.1	—	74.6	86	6.8	141.60	—	167	—	—
Lagos, Nigeria ..	1012.0	+1.2	94	60	87.2	70.5	78.9	−1.8	75.9	84	8.2	35.95	—	112	4.7	39
Kaduna, Nigeria ..	1010.5	—	99	54	87.6	64.9	76.3	−0.9	65.2	54	6.2	50.87	−2.96	105	7.3	61
Chileka, Nyasaland ..	1016.6	+0.1	97	48	81.9	63.2	72.5	+0.5	64.8	66	4.6	32.70	−3.38	80	6.8	56
Lusaka, Rhodesia ..	1014.1	+0.3	97	43	80.2	58.6	69.4	+0.4	60.4	66	4.8	34.48	−2.79	92	7.5	62
Salisbury, Rhodesia ..	1016.1	0.0	91	35	76.5	54.4	65.4	+0.2	57.2	64	3.8	31.80	−1.64	96	7.4	61
Cape Town ..	—	—	103	33	—	—	—	—	—	—	—	23.07	−1.97	136	—	—
Germiston, South Africa	1017.9	+0.6	92	24	72.9	50.3	61.6	+0.8	50.6	61	2.9	20.40	−5.14	77	9.0	75
Mauritius																
Calcutta, Alipore Obsy.	1006.9	−0.7	100	53	88.4	72.3	80.3	+1.5	73.2	85	5.0	67.49	+3.17	130	6.9	57
Bombay	1008.3	−0.9	95	61	87.7	75.6	81.7	+1.1	74.0	80	4.7	71.74	−0.45	91	7.2	60
Madras	1008.3	−0.5	110	65	92.1	76.4	84.3	+1.2	74.9	77	5.8	34.09	−15.47	82	7.9	65
Colombo, Ceylon ..	1010.1	+0.4	92	69	86.7	75.1	80.9	−0.1	75.1	87	6.5	74.85	−5.28	188	7.3	60
Singapore	1009.6	+0.1	95	71	87.7	75.1	81.4	+0.5	76.6	83	7.3	104.78	+9.66	197	—	—
Hongkong	1012.5	0.0	92	39	78.5	68.9	73.7	+1.4	69.2	82	—	97.75	+12.02	180	5.1	42
Sydney, N.S.W. ..	1015.8	−0.1	97	38	70.4	55.5	62.9	−0.2	56.5	67	5.1	38.83	−8.65	129	7.2	60
Melbourne	1015.5	−0.8	104	30	67.1	48.8	58.0	−0.4	51.6	65	6.4	20.98	−4.49	155	5.5	45
Adelaide	1017.6	+0.5	110	37	70.2	52.5	61.3	−1.7	53.4	57	6.2	21.40	+0.25	122	6.6	54
Perth, W. Australia ..	—	—	107	39	74.6	55.5	65.1	+0.9	58.3	60	4.1	34.75	+0.38	115	7.7	64
Coolgardie																
Brisbane	1015.9	0.0	96	37	77.3	59.5	68.4	−0.5	61.3	65	4.4	41.54	−3.75	106	8.1	67
Hobart, Tasmania ..																
Wellington, N.Z. ..																
Suva, Fiji	1010.8	−0.5	91	60	81.6	72.1	76.9	−0.1	73.2	83	7.5	120.40	+3.26	243	5.0	41
Apia, Samoa ..	1009.9	−0.1	93	67	86.1	73.7	79.9	+0.4	76.9	80	6.8	141.48	+29.48	238	6.7	55
Kingston, Jamaica ..	1013.7	0.0	95	65	89.4	72.6	81.0	+1.7	73.9	75	3.9	37.82	+4.23	65	8.3	68
Grenada, W. Indies ..	—	—	—	61	—	75.2	—	—	76.0	79	7.5	57.35	−17.24	241	—	—
Toronto	1017.2	+0.6	101	−12	55.6	39.8	47.7	+2.5	40.7	74	6.5	28.44	−2.85	127	5.5	45
Winnipeg	1015.6	−0.6	95	−36	46.9	26.4	36.7	+2.1	28.4	80	5.5	15.92	−4.26	104	6.1	50
St. John, N.B. ..	1015.9	+1.3	87	−15	49.5	34.0	41.7	+0.5	37.1	86	6.4	48.88	+0.80	175	5.2	43
Victoria, B.C. ..	1016.3	−0.4	81	20	55.2	40.9	48.1	−1.3	42.5	91	6.4	43.28	+12.97	165	5.7	47

RAINFALL OF APRIL 1949

Great Britain and Northern Ireland

County	Station	In.	Per cent of Av.	County	Station	In.	Per cent of Av.
London	Camden Square ..	1·65	107	*Glam.*	Cardiff, Penylan ..	3·02	121
Kent	Folkestone, Cherry Gdn.	1·85	111	*Pemb.*	St. Ann's Head ..	2·89	141
,,	Edenbridge, Falconhurst	1·79	96	*Card.*	Aberystwyth	3·29	160
Sussex	Compton, Compton Ho.	2·23	111	*Radnor*	Tyrmynydd	5·13	139
,,	Worthing, Beach Ho.Pk.	1·16	74	*Mont.*	Lake Vyrnwy	7·33	228
Hants	Ventnor, Roy. Nat. Hos.	1·17	70	*Mer.*	Blaenau Festiniog ..	11·41	185
,,	Bournemouth	1·78	99	*Carn.*	Llandudno	2·12	125
,,	Sherborne St. John ..	1·91	108	*Angl.*	Llanerchymedd ..	2·50	113
Herts.	Royston, Therfield Rec.	1·60	102	*I. Man.*	Douglas, Borough Cem.	3·24	133
Bucks.	Slough, Upton	1·17	82	*Wigtown*	Port William, Monreith	2·69	122
Oxford	Oxford, Radcliffe ..	1·31	82	*Dumf.*	Dumfries, Crichton R.I.	2·97	126
N'hant.	Wellingboro', Swanspool	1·53	103	,,	Eskdalemuir Obsy. ..	6·45	190
Essex	Shoeburyness	1·35	112	*Roxb.*	Kelso, Floors	1·35	86
Suffolk	Campsea Ashe, High Ho.	1·23	87	*Peebles*	Stobo Castle	2·56	123
,,	Lowestoft Sec. School ..	1·33	90	*Berwick*	Marchmont House ..	1·02	50
,,	Bury St. Ed., Westley H.	1·84	120	*E. Loth.*	North Berwick Res. ..	·98	70
Norfolk	Sandringham Ho. Gdns.	2·19	144	*Midl'n.*	Edinburgh, Blackf'd. H.	1·07	73
Wilts.	Bishops Cannings ..	1·34	66	*Lanark*	Hamilton W. W., T'nhill	3·14	168
Dorset	Creech Grange.. ..	1·98	92	*Ayr*	Colmonell, Knockdolian	4·06	160
,,	Beaminster, East St. ..	2·29	97	,,	Glen Afton, Ayr San ..	5·62	187
Devon	Teignmouth, Den Gdns.	1·55	77	*Bute*	Rothesay, Ardencraig	6·77	227
,,	Cullompton	1·82	80	*Argyll*	L. Sunart, Glenborrodale	8·20	196
,,	Barnstaple, N. Dev. Ath.	2·10	99	,,	Poltalloch	6·36	211
,,	Okehampton, Uplands	3·09	97	,,	Inverary Castle ..	12·36	269
Cornwall	Bude School House ..	1·79	95	,,	Islay, Eallabus ..	6·10	213
,,	Penzance, Morrab Gdns.	1·85	76	,,	Tiree	5·46	222
,,	St. Austell, Trevarna ..	1·86	66	*Kinross*	Loch Leven Sluice ..	2·29	119
,,	Scilly, Tresco Abbey ..	1·23	63	*Fife*	Leuchars Airfield ..	·98	62
Glos.	Cirencester	1·71	91	*Perth*	Loch Dhu		
Salop.	Church Stretton ..	2·52	116	,,	Crieff, Strathearn Hyd.	2·59	118
,,	Cheswardine Hall ..	2·47	141	,,	Pitlochry, Fincastle ..	2·78	125
Worcs.	Malvern, Free Library	2·40	133	*Angus*	Montrose, Sunnyside ..	1·95	107
Warwick	Birmingham, Edgbaston	2·39	137	*Aberd.*	Braemar	2·28	96
Leics.	Thornton Reservoir ..	2·45	144	,,	Dyce, Craibstone ..	·92	45
Lincs.	Boston, Skirbeck ..	1·79	133	,,	Fyvie Castle	1·19	56
,,	Skegness, Marine Gdns.	2·11	157	*Moray*	Gordon Castle	1·28	73
Notts.	Mansfield, Carr Bank ..	1·78	103	*Nairn*	Nairn, Achareidh ..	2·08	149
Derby	Buxton, Terrace Slopes	4·74	161	*Inv's*	Loch Ness, Foyers ..	2·56	118
Ches.	Bidston Observatory ..	2·50	153	,,	Glenquoich	15·40	237
Lancs.	Manchester, Whit. Park	2·64	137	,,	Fort William, Teviot ..	12·00	267
,,	Stonyhurst College ..	5·28	195	,,	Skye, Duntuilm ..	5·12	158
,,	Blackpool	2·98	159	*R. & C.*	Ullapool	3·81	126
Yorks.	Wakefield, Clarence Pk.	2·06	123	,,	Applecross Gardens ..	5·47	160
,,	Hull, Pearson Park ..	2·19	140	,,	Achnashellach	11·73	219
,,	Felixkirk, Mt. St. John	2·29	137	,,	Stornoway Airfield ..	4·19	145
,,	York Museum	2·48	155	*Suth.*	Lairg		
,,	Scarborough	2·00	128	,,	Loch More, Achfary ..	7·88	163
,,	Middlesbrough.. ..	2·02	147	*Caith.*	Wick Airfield	1·75	88
,,	Baldersdale, Hury Res.	3·50	145	*Shetland*	Lerwick Observatory ..	3·25	142
Norl'd.	Newcastle, Leazes Pk. ..	1·36	86	*Ferm.*	Crom Castle	3·11	121
,,	Bellingham, High Green	1·77	82	*Armagh*	Armagh Observatory ..	2·18	104
,,	Lilburn Tower Gdns. ..	1·10	56	*Down*	Seaforde	2·17	83
Cumb.	Geltsdale	2·98	140	*Antrim*	Aldergrove Airfield ..	1·94	92
,,	Keswick, High Hill ..	7·17	234	,,	Ballymena, Harryville..	2·56	97
,,	Ravenglass, The Grove	3·31	133	*L'derry*	Garvagh, Moneydig ..	2·46	101
Mon.	Abergavenny Larchfield	3·01	119	,,	Londonderry, Creggan	5·10	198
Glam.	Ystalyfera, Wern House	5·78	152	*Tyrone*	Omagh, Edenfel ..	3·78	144